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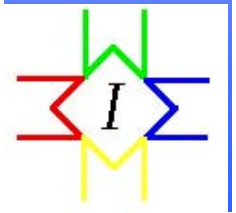

Multi-modal Interfacing for Human-Robot Interaction

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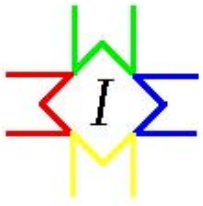
Objectives of Natural Language/Gesture Research

- **Use a dialog-based approach to achieve:**
  - Integrated multi-modal interface in a robotics domain
  - Dynamic autonomy
- **Seamlessly integrate natural language and gestural communication**
  - Ambiguous natural language utterances without gestures
    - deixis
      - "Go over there" <with/out gestures>
  - Contradictory inputs
    - "turn left" <while pointing right>
    - "Natural" and "synthetic" gestures coupled with speech and buttons
  - **Develop continuous dialog with/out interruptions**
  - **Facilitate dynamically changing levels of autonomy and interaction**



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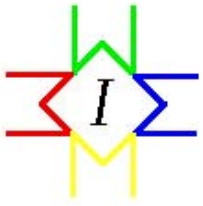
Working Hypotheses

- **Linguistic Hypothesis:**
  - Gesture disambiguates and contributes information in human-human dialog
- **Gestural Hypothesis:**
  - Gesturing is natural in human-human dialog
    - Hand/arm movement vs. Electronic devices, e.g. mouse, light-pen, or touch-screen
- **Assumption of natural language/robotics research**
  - "...With just a very few human-like cues from a humanoid robot, people naturally fall into the pattern of interacting with it as if it were a human."--
    - Quote taken from The COG Shop website: http://www.ai.mit.edu/projects/cog/

And as we all know,

- humans can be pretty independent
- humans desire human-like cooperation in the systems they design



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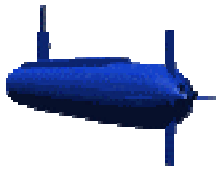
Dynamic Autonomy

- **Re-deployment during mission interspersed with periods of autonomy**
  - **Micro air vehicles launched**

  - **autonomous underwater vehicles**



  - **planetary rover**

Mixed-Initiative Systems and Dynamic Autonomy

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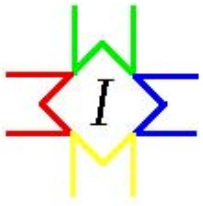
- Command and control situations
  - Characterized by tight human/robot interactions.
  - Instantiating a goal is a function of either agent in these situations.
    - These are by definition “Mixed-initiative” systems.
- Levels of independence, intelligence and control are necessary in “mixed-initiative” systems
  - Dynamic autonomy is necessary to achieve these varying levels.



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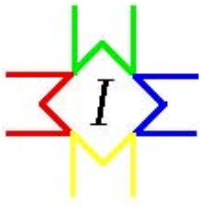
Hardware and Software

- COTS speech recognizer
  - IBM ViaVoice Pro Millennium Edition
- NAUTILUS natural language processor
  - In-house natural language understanding system
    - Programming in Allegro Common Lisp and C++ on PCs
    - Programming in Gnu Common Lisp and C++ on Suns
  - Messages are passed via “foreign functions” between modules in a kind of “blackboard” architecture
- COTS mobile robots
  - Nomadic Technologies 200 and XR-4000 mobile robots
  - RWI ATRV-Jr.
- Personal Digital Assistant
  - Palm family, e.g. 3 COM Palm V Organizer



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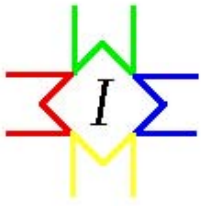
Linguistic Constructs

- We are using two linguistic variables, “context predicates” which contain location information and goals, to track both interrupted and non-interrupted goal completion in a command, control and interaction environment (“C_2I”).
- Context predicates and goal information are being used to enable greater independence and cooperation between agents in a C_2I environment.



Predicates and Goals

- **CONTEXT PREDICATES**
  - a stack of goals and their status (attained vs. unattained)
- **GOALS**
  - Event goals
    - “turn left/right”--arriving at the final state of having turned in a particular direction
  - Locative goals
    - “there” “the waypoint” “table”

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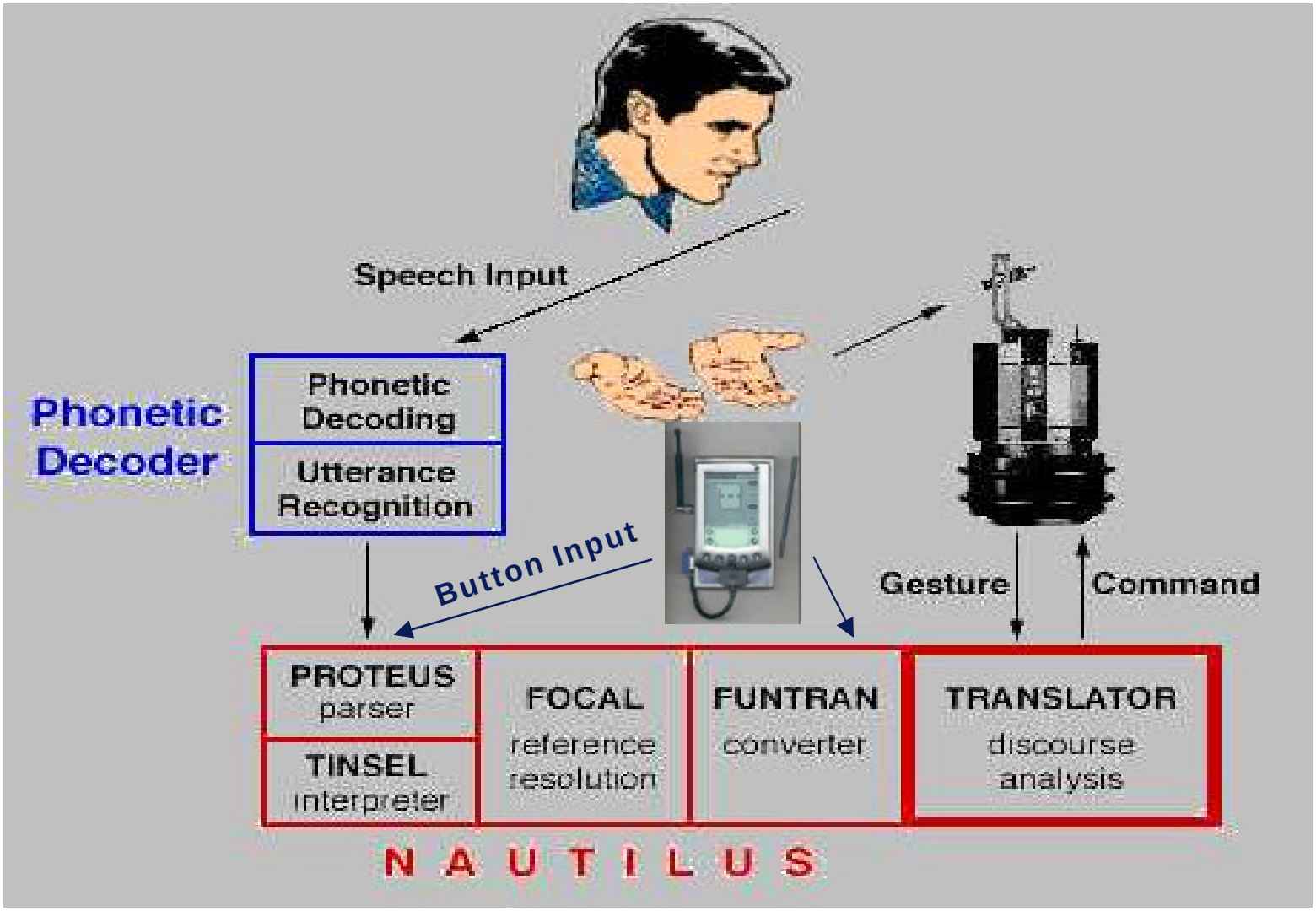
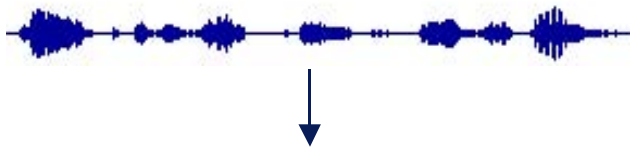
Object and Gesture Recognition

- Structured-light range finder (camera + laser)
  - output: 2D range data
- 16 ultra-sonic sonars
  - output: range data out to 25’
- 16 active infrared sensors
  - output: delta of ambient light and current light (detects if object present)
- bumpers for collision avoidance

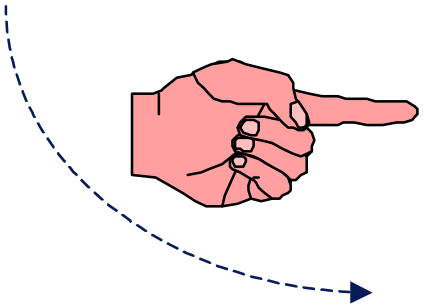
Interaction with NL Component



Processing Speech and Gesture



GO TO THE WAYPOINT OVER THERE



(IMPER (:VERB GESTURE-GO
(:AGENT (:SYSTEM YOU))
(:TO-LOC (WAYPOINT-GESTURE))
(:GOAL (THERE))))

(2 42 123456.123456 0)

(sending message: “17 42 0”)

Processing PDA Commands & Gestures

Go To

Palm-click:
X = 30
Y = 120

(0x83)

(30 120)

(sending message: “17 30 120”)

Integrated Inputs

GO OVER THERE

Palm-click:
X = 30
Y = 120

(IMPER (:VERB GO
(:AGENT (:SYSTEM YOU))
(:TO-LOC (HERE)))

(30 120)

(sending message: “17 30 120”)

Diagram of Multi-modal Interface

Spoken Commands

PDA Commands

PDA Gestures

Natural Gestures

Command Interpreter

Gesture Interpreter

Goal Tracker

Appropriateness/Need Filter

Robot Action

Speech Output (requests for clarification, etc.)

TYPES of DATA CURRENTLY HANDLED

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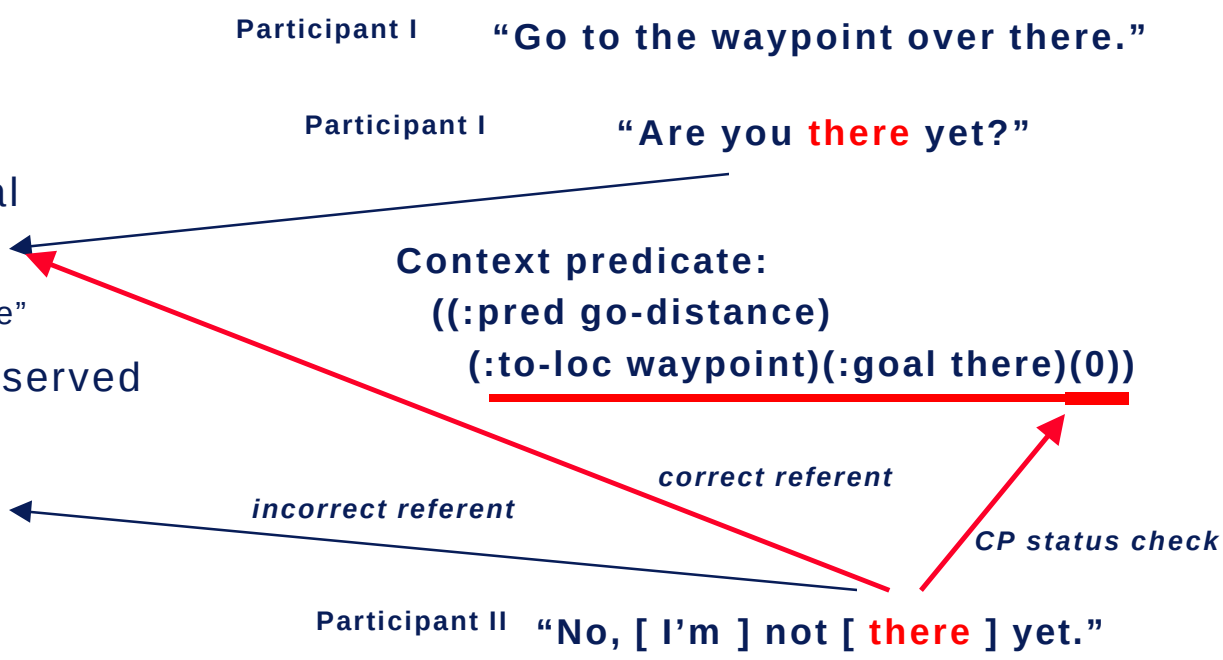
- **Simple commands**
  - Roadrunner, turn left.
  - Coyote, go to waypoint 1.
  - **Line Segment commands** (with/out natural/PDA gesture)
    - Roadrunner, move back ten inches.
    - Coyote, move up this far.
  - **Vectoring commands** (with/out natural/PDA gesture)
    - Roadrunner, turn left 30 degrees.
    - Coyote, turn right this far.
- **Complex commands** (with/out natural/PDA gesture)
  - Roadrunner/Coyote, go to the waypoint over there.
- **Interrupted sequences**
  - Coyote, go over there.
  - Where?
  - Coyote, over there.
  - Roadrunner, go to waypoint 2.
  - Roadrunner, stop.
  - Roadrunner, continue (to waypoint 2/3).

Disambiguating Locative Data

Systems having robust vision capabilities and complex goal-directed activity can have locative reference problems. As in the following dialog where the system sees something prior to the completion of a goal. Using a status check of the "context predicate" disambiguates the referent.

- **Object list**
  - Locative goal
    - waypoint
      - "there"
  - Object(s) observed
    - chair
    - table



Data we still want to handle

- A typical dialog with two or more autonomous robots:
  - 1. Roadrunner, go to waypoint 1.
  - 2. Coyote, go to the door over there.
  - 3. Roadrunner, stop.
  - 4. Coyote, stop but now continue doing what Roadrunner was doing.
  - 5. Roadrunner, I want you to go to the door instead.
- Above interchange requires additional dialog capabilities
  - fill in “elliptical information”
    - “doing what Roadrunner was doing” (sentence 4 above).
  - disambiguate referents across the dialog,
    - “the door” in sentence 5.
- Self-appointed team membership
  - Given a particular goal or goals and several robots tasked to complete the goal(s), robots assign themselves to various teams to complete the task.

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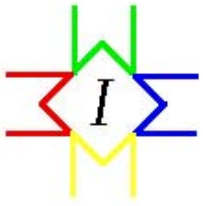

Additional Requirements: Interleaved Planning

- **Predicate List** — **GOAL STACK (attained?)**
  - go to object <locative> — NO
  - stop — YES
  - go to object <table> — YES
  - pick up object <book> — YES
  - go to object <locative> — NO

situation, plan of action, goals unknown to speaker occur

  - **move obstacle <X>*
    - *<determine if moveable>*
      - *<if not, report>*
      - *<if moveable, determine how>*
    - *<if moveable by self, move obstacle <x>>*
    - *<if not, acquire assistance>*
      - *<move obstacle <x>*
      - *<re-deploy assistant>* — *YES*
  - go to object <locative> — YES

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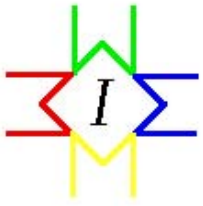
Conclusions

1. By using “context predicates” we track actions occurring during a dialog to determine which goals (event and locative) have been achieved or attained and which have not.

2. By tracking “context predicates” we can determine what actions need to be acted upon next; i.e. predicates in the stack that have not been completed.

3. “Locative” expressions, e.g. “there,” give us a kind of handle in command and control applications to attempt error correction when locative goals are being discussed.

4. By interleaving complex dialog with natural and mechanical gestures, we hope to achieve dynamic autonomy and an integrated multi-modal interface.



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Future Plans

- Extend gesture recognition via better vision capabilities, etc.

- Integrate symbolic gestures with natural gestures
  - ASL, canine obedience, etc.
    -- for use in noisy or secure environments

- Integrate 3D audio with multimodal interaction
  - orientation of speaker and “hearer” and directionality issues between participants

- Integrate speaker recognition via visual input

- Develop dialog-based planning for teams of dynamically autonomous robots

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Video Clip

QuickTime™ and a
Cinepak decompressor
are needed to see this picture.